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SECTION III.—FORECASTS.

FORECASTS AND WARNINGS FOR MARCH, 1916.

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[Dated: U. S. Weather Bureau, Washington, D. C., Apr. 1, 1916.]

GENERAL PRESSURE DISTRIBUTION OVER THE UNITED STATES AND CANADA, INCLUDING THE HAWAIIAN AND ALEUTIAN ISLANDS, ALASKA, AND THE WESTERN PORTION OF THE MIDDLE ATLANTIC OCEAN.

High pressure prevailed quite generally over the Aleutian Islands and northern Alaska during the first half of the month, and moderately low pressure during the second half, as a rule. Over the South Pacific Ocean, as indicated by the observations at Honolulu, the reverse conditions obtained, except during the last week of the month when conditions were nearly normal. Over southern Alaska low pressure predominated with marked depressions on the 5th and 6th and on the 21st and 22d. There were but two brief periods of above-normal pressure, one between the 11th and 14th and the other from the 28th until the close of the month.

Over the North Pacific States there were alternating periods of moderate departures from the normal pressure, each about one week in length, beginning with low pressure during the first week. Over the South Pacific States changes during the month were not of consequence.

From the Plateau Region eastward and southeastward there was a constant series of high and low pressure areas at intervals of about three days, and some of these were of pronounced character and extremely rapid movement, notably the low area that was first noted on the 5th over southern Alaska, reaching the Atlantic coast about three days later, and also the disturbance that first appeared over Alberta on the evening of the 19th, reaching the middle Atlantic coast three days later. The principal high pressure area of the month began with the 14th over Alberta and swept southeastward to the Gulf coast during the succeeding four or five days. Over the western Atlantic Ocean, as indicated by reports from Bermuda and Turks Island, there were rapid alternations of moderately high and moderately low pressure, until the last week of the month when low pressure prevailed continuously.

STORM WARNINGS.

On the morning of March 1 a disturbance of marked character was central over western Oklahoma with an extensive high pressure area and a cold wave to the northward. This disturbance moved southeastward to the mouth of the Rio Grande and thence northeastward by way of Georgia to the North Carolina coast and thence to the Gulf of St. Lawrence, increasing steadily in intensity as it progressed, so that by the morning of March 5 the barometer at Port aux Basques read 28.84 inches. On the morning of the 3d the storm was central off the Carolina coast, but no strong winds had as yet occurred and northwest storm warnings were ordered from Jacksonville to New York, and northeast warnings on the New England coast eastward as far as Cape Cod. Small-craft warnings were also ordered on the Florida

coast as far as Fort Pierce. As the storm reached the Virginia coast, it was attended by snows that extended northward into New England and strong northerly gales prevailed during the afternoon and night of the 3d from Jacksonville to Eastport, and also on the 4th from North Carolina northward. On the morning of the 4th a disturbance from the Pacific was central over British Columbia. It moved rapidly southeastward with steadily increasing intensity, and on the morning of the 6th was central over Iowa with moderately high pressure to the eastward. Special observations indicated a further increase in intensity and at 5 p. m. southeast storm warnings were ordered from Delaware Breakwater to Portland, Me. During the following night strong winds occurred on the New England coast and on the morning of the 7th, when the storm was central over Georgian Bay, southeast warnings were also ordered for the balance of the Maine coast, and strong winds occurred as forecast. During the 7th the disturbance divided, with one center over southern Virginia and another over southern Lake Huron. In view of the probable development of the Virginia section, northeast storm warnings were ordered at 10 a. m. of the 8th from Sandy Hook to Boston, and at 11 a. m. northwest warnings southward to Savannah, Ga. At 2:30 p. m. the northeast warnings were extended along the entire New England coast and during the day and night of the 8th strong gales occurred as indicated, with velocities on the New England coast reaching from 52 to 56 miles an hour with quite heavy snow. Along the south Atlantic coast only moderate gales occurred. On the morning of the 9th, with pressure of 28.92 inches at Eastport, Me., the warnings from Sandy Hook eastward were changed to northwest and fresh to strong westerly gales occurred during the day. At 9 p. m. the warnings were lowered.

In the meantime another disturbance from the North Pacific appeared over British Columbia on the morning of the 7th, and by the morning of the 10th it had reached the upper St. Lawrence Valley in well-defined formation. At 10:30 a. m. southwest storm warnings were ordered from Delaware Breakwater to Eastport, with instructions to change the same to northwest at sunset. Moderate gales occurred during the afternoon and night of the 10th as far south as Norfolk, Va. Another disturbance from the Northwest quickly followed and passed off the New England coast during the 13th. Only moderately strong winds occurred, except at Nantucket, and no warnings were ordered. Falling pressure during the 12th over Kansas developed a disturbance that, by the morning of the 14th, extended as a trough from northern Texas through the Ohio Valley with three centers of disturbance, the forward one over West Virginia. As the 8 p. m. map showed evidences of further development of the center over West Virginia and the dissolution of those to the southwestward, northeast storm warnings were ordered from Cape Henry, Va., to Eastport, Me., for it was apparent that the storm would continue eastward off the Virginia coast. On the morning of the 15th northwest warnings were ordered south of Cape Henry as far as Jacksonville, and during the day fresh gales occurred along the entire coast from Jacksonville northward. The storm center had turned northeastward after reaching the

Virginia coast, and the warnings, changed to northwest, were continued from Delaware Breakwater northward except at Eastport, Me. The winds did not subside until during the night of the 16th-17th.

During the night of the 19th a disturbance appeared over Alberta and moved southeastward with rapidly increasing intensity, so that by the night of the 21st it was central over western Missouri with a barometer reading of 29.18 inches at Kansas City. As there was quite a strong gradient to the southward, small-craft warnings were ordered displayed on the 22d on the middle coast of the Gulf of Mexico, and fresh to strong south and southwest winds were forecast. These occurred as indicated. On the morning of the 22d the disturbance was central over southern Ohio with a still further increase in intensity. Southeast storm warnings were ordered at 9:25 a. m. from Delaware Breakwater to Eastport, with advices reading that strong gales and snow were expected, with winds shifting to north and northwest with continuing gales and much colder. Southwest warnings were also ordered at the same time southward as far as Jacksonville and strong southwest to west gales were forecast. This proved to be the most severe storm of the month. Strong gales occurred along the entire coast from northern Florida northward, accompanied on the middle Atlantic and New England coasts by quite heavy snowfall. The storm continued rapidly eastward, and on the morning of the 23d was central off the coast of Nova Scotia, with a barometer reading of 28.92 inches. Moderately strong westerly winds were prevailing, but the storm warnings were not renewed.

The rapid succession of the northwestern disturbances continued, and on the night of the 23d another of marked intensity was central over eastern Colorado. On the morning of the 24th there were two centers of disturbance—one over eastern Nebraska and another over western Colorado. Both moved eastward with decreasing intensity, but the southern one was sufficient to cause fresh to strong southerly winds on the east Gulf coast, for which southeast storm warnings were ordered at 10 p. m. of the 24th. This disturbance, in marked contrast to its predecessors, moved very slowly eastward, taking four days to make the journey from the middle Mississippi Valley to the North Carolina coast. On the night of the 27th, when the principal section of the disturbance was central over North Carolina, its further development was more or less uncertain and advisory messages of fresh to strong northeast winds were distributed along the middle Atlantic and southern New England coasts, but storm warnings were not ordered, as it was not thought that they would be necessary. Conditions on the following morning indicated that this view was correct, but small-craft warnings were ordered from Delaware Breakwater to New York and moderately strong winds occurred. On the morning of the 29th the disturbance still persisted off the North Carolina coast with some faint evidences of development to the northeastward and northeast storm warnings were accordingly ordered for Block Island, R. I., and Nantucket, Mass., only. There were some strong winds during the day, but none of consequence, and at 9 p. m. the warnings were lowered.

In addition to these warnings, small-craft warnings were ordered at various times on the Gulf coast for the fresh and moderately strong winds that occurred.

While the northwestern storms were making their rapid progression across the central portion of the country, cautionary advices to open ports on Lake Michigan became necessary at times and such were

ordered on the night of the 5th, warning that gales might be expected on the following day; on the morning of the 9th, for strong southwesterly winds; and again on the evening of the 21st for strong northeast to north winds, possibly gales with snow and rain. These advisory warnings were justified in each instance.

COLD WAVES AND FROSTS.

A marked high pressure area with low temperatures followed the storm of the early days of the month, and on the morning of the 3d cold-wave warnings were ordered for North Carolina, South Carolina, Georgia, and the northern and central portions of Florida. These warnings were verified by the occurrences on the 4th of freezing temperatures to the Georgia-Florida line and by heavy frosts in northwest Florida. However, the fall in temperature advanced eastward more rapidly than had been anticipated and the cold wave had already covered the interior of the Southern States on the afternoon of the 3d, following a forecast of colder weather made on the previous day. On the morning of the 4th, with marked high pressure and low temperatures prevailing over the South, frost warnings were issued for Florida as far south as the interior of the southern portion. Heavy to killing frosts occurred on the morning of the 5th as indicated. On the morning of the 8th, with high pressure and low temperatures prevailing over Texas following a disturbance that was passing up the Atlantic coast, frosts were forecast for South Carolina, southwest Georgia, and the east Gulf States, and on the morning of the 9th frost occurred as forecast in South Carolina, Georgia, and Florida, but none was reported from Alabama and Mississippi, although freezing temperatures occurred in portions of the two last-mentioned States. As pressure conditions had not changed materially, warnings were issued on the morning of the 9th for freezing temperature or heavy frost in the Carolinas and for frost in Georgia and the central and northeast portions of Florida, which forecasts were fully verified by the occurrences on the following morning.

On the morning of the 11th a moderate disturbance was moving off the Georgia coast with a cold high area to the northwestward; warnings of frost and freezing temperature were issued for South Carolina, and freezing temperatures were reported on the following morning with heavy frost extending into southern Georgia. These Georgia and Alabama frosts had already been forecast on the morning of the 11th. There was no prospect of any immediate change of conditions over the Southeastern States, and accordingly frost warnings were ordered on the morning of the 12th for the interior of South Carolina, for northern and central Florida, and for Georgia. The frosts occurred on the morning of the 13th as forecast.

At this time the high pressure area from the Canadian Northwest had reached Lake Superior, accompanied by falling temperatures, but as it was thought that there could be no further decided fall in temperature, no warnings were ordered for the cold waves that actually occurred on the morning of the 14th over the eastern and southern portions of upper Michigan, where the temperatures were 0° F. or slightly below. Nor were cold-wave warnings ordered over the Ohio Valley, Tennessee, and the South for the cold wave that occurred on the morning of the 15th, although colder weather had been forecast over practically this entire district. This cold wave was caused by the rapid eastward movement of the low pressure area of the 14th that extended from

Texas to the upper Ohio Valley, and of the strong cold high area to the northwestward. On the night of the 14th, however, warnings of frost or freezing temperature were sent to stations in Alabama and Mississippi, and on the morning of the 15th to Mississippi, Alabama, northern and central Florida. Cold-wave warnings were also ordered for North Carolina and warnings of frost and freezing temperature for the interior of South Carolina, eastern and southern Georgia, and southwestern Virginia, and on the following morning conditions were as had been forecast.

On the morning of the 16th, with cold high pressure still prevailing throughout the West and South, warnings of freezing temperature or lower were sent to North Carolina, South Carolina, Georgia, and northern and central Florida and warnings of frost in central Florida as far down as the twenty-sixth parallel. On the morning of the 17th frost occurred as far south as the northern suburbs of Miami, Fla. As conditions were changing but slowly, frost warnings were repeated on the morning of the 17th for the Carolinas, Georgia, and northern and central Florida, as far south as the twenty-seventh parallel, and again frosts occurred as forecast.

On the morning of the 22d the great storm of the month was central over southern Ohio, with a high area over Manitoba moving southeastward. Accordingly, cold-wave warnings were ordered for Kentucky, Indiana, central and southern lower Michigan, Ohio, West Virginia, and the southern portion of western Pennsylvania, and frost warnings for Tennessee and the northern portions of Alabama and Mississippi. These forecasts were verified, except in a few scattered localities where the fall in temperature was not sufficient to technically justify the cold-wave warnings. The minimum temperatures reached were much below the required limit however. On the morning of the 23d, with moderately high pressure over the Ohio Valley, warnings were issued for freezing temperature in Virginia, heavy frosts in North Carolina, and frosts in South Carolina, northern and central Georgia, and central and eastern Tennessee. These forecasts were not verified, as the rapid approach of a disturbance from the extreme West caused east and southeast winds with increasing cloudiness.

On the morning of the 26th, with a slowly moving disturbance central over Missouri and marked high pressure over the central Rocky Mountain region, frost warnings were ordered for Alabama, Mississippi, western and southern Tennessee, and extreme northwestern Florida, contingent upon the weather clearing. Cold-wave warnings were also ordered for northwestern Ohio, northeastern Indiana, and Michigan. At the time these warnings were made the western disturbance had been progressing at a fair rate and the forecasts were predicated upon the assumption that this rate would be maintained. However, the succeeding 24-hour movement was very slight and, as a consequence, the cold-wave and frost forecasts were failures. On the morning of the 27th frost warnings, predicated upon clearing weather, were again issued for northwestern South Carolina, northern and central Georgia, Alabama, Mississippi, and Tennessee, and on the morning of the 28th frosts occurred as forecast, except in central and eastern Tennessee, where cloudy weather continued.

On the morning of the 28th frosts were forecast for North Carolina, interior South Carolina, northern and western Georgia, the northern portions of Alabama and Mississippi, and for Tennessee. Frosts occurred on the following morning over Tennessee and the east Gulf

districts, but failed in the Carolinas and Georgia on account of the slow movement of the low pressure area above referred to. On the 30th, with high pressure prevailing generally east of the Mississippi River, frosts were forecast for southeastern Georgia, northwestern South Carolina, and the interior of North Carolina, and were verified except in Georgia. On the morning of the 31st frost warnings were also issued for southeast Virginia, and on the morning of April 1 light frost was reported.

DISTRICT WARNINGS DURING MARCH.

Chicago District.—During the night of March 8-9, 1916, a disturbance moved rapidly southeastward from Saskatchewan to western Lake Superior, followed by rapidly rising barometer and a marked fall in temperature in the Saskatchewan Valley. Cold-wave warnings were issued on the morning of the 9th for North Dakota and northern Minnesota, and later in the day were extended to cover southern Minnesota, southern Wisconsin, northeastern Iowa, and extreme northern Illinois. No other warnings were issued during the month, except on the morning of the 25th, when cold-wave warnings were ordered for the upper Mississippi and lower Missouri Valleys, a disturbance being centered over Missouri at that time, with increasing pressure attended by lower temperature in the trans-Missouri region.

The only frost warning issued was that for Cairo, Ill., on the 27th.—*Charles L. Mitchell, Assistant Forecaster.*

Denver District.—Cold-wave warnings were issued on the morning of March 2 for southwestern Colorado, northwestern New Mexico and northeastern Arizona, and were fully verified. Cold-wave warnings were again issued on the morning of the 23d for western Utah, and on the evening of that date for eastern Colorado and eastern New Mexico. These were verified except in the vicinity of Pueblo and in southeastern New Mexico. On account of the forward season, warnings of frost and freezing temperatures were necessary earlier than usual. Warnings were issued almost daily for some part of the district after the 22d, and were fully verified except near the close of the month in the vicinity of Salt Lake City and in southeastern New Mexico.—*F. H. Brandenburg, District Forecaster.*

New Orleans District.—On the morning of March 1, a cold-wave warning was issued for Abilene, Tex. Small-craft warnings were ordered for stations on the Texas coast on the 14th, 21st, and 23d. On the 25th a small-craft warning was issued for New Orleans. Frosts occurred on several dates as far south as the berry region, for all of which warnings were issued. On two dates conditions indicated the probable occurrence of frost, and warnings of probable frosts in a portion of the district were issued, but not verified.—*William B. Stockman, Assistant Forecaster.*

Portland, Oreg., District.—Live-stock warnings were issued on March 2 and 4. They were in continuation of the warning issued on February 28 and extended on the 29th to cover all sections where such warnings were desired. These warnings were well verified. Most of the storm warnings issued were general, and all were verified in whole or part except that of the 19th. The most severe storm occurred on the 21st, an 80-mile southerly gale having been reported from the mouth of the Columbia River.

Of the frost warnings sent out, those on the 17th, 24th, and 25th were not verified. Fruit buds in several localities were far enough advanced to be susceptible to damage from freezing temperatures and several of the warn-

ings sent to the Rogue River Valley were not specially timely or accurate.—*T. Francis Drake, Local Forecaster.*

San Francisco District.—The only important warnings issued during March were those for frosts on the 23d and 24th. Frosts occurred quite generally on the mornings of the 24th and 25th, but moderate winds and some cloudiness prevented any serious injury.—*G. H. Willson, District Forecaster.*

ON PRESSURE-CHANGE CHARTS.

By EDWARD H. BOWIE, District Forecaster.

[Dated: Washington, Nov. 27, 1915.]

An important change in the construction of the pressure-change charts prepared at the central office of the Weather Bureau became effective on August 1, 1915. During many years previous to this date there were entered on these charts the 24- and 12-hour changes and the departure from the normal sea-level pressures for all stations from which both the 8 a. m. and 8 p. m. (seventy-fifth meridian time) observations were received by telegraph from the area comprising the United States and southern Canada. The 12-hour changes were made after the application in each case of a correction for the diurnal fluctuation that made the 8 a. m. comparable with the pressure observed at the previous 8 p. m. observation, and similarly the 8 p. m. with the pressure at the preceding 8 a. m. observation. There was obviously no correction necessary in making the 24-hour changes. The pressure changes having been computed, lines (isallobars) in red were drawn for each 0.10 inch rise and fall in 24 hours and a heavier red line drawn through points of no change. Similarly, blue lines (isallobars) for each 0.10 inch rise and fall were drawn for the 12-hour pressure changes. The revised chart omits the 24-hour changes and the red lines drawn to these changes. On the new chart isobars for sea-level pressures are drawn in red and superposed on these are blue lines (isallobars) drawn through points having equal 12-hour changes, a line being drawn through each 0.10 inch fall or rise and a heavier line for zero change. In addition to these lines, the "barometric tendency" or pressure change in the two hours immediately preceding the time of observation at any station is entered in green figures when telegraphed. The "barometric tendency" is telegraphed from selected stations only when the change in pressure equals or exceeds 0.04 inch in the two hours immediately preceding the observation. Figures 1 and 2 (Chart XLIV-34, 35) show the old form of pressure-change maps, and figures 3 and 4 are reproductions of the revised maps. The "barometric tendency" is indicated by large bold-faced figures in red.

The change was made that the forecaster might see at once the relation between the highs and lows and the pressure changes that have taken place during the time between the current observation and that which immediately preceded it, and it is the consensus of opinion of the forecasters at the central office of the Weather Bureau that the new form of pressure-change chart has many advantages over the one previously in use and is a valuable aid in forecast work.

¹ The preparation of pressure-change charts in the Forecast Division, U. S. Weather Bureau, began in 1872, when observations were telegraphed thrice daily and charts for 8-hour intervals were prepared until June 20, 1888.

Figures E. H. B. 1 to E. H. B. 8 form charts XLIV-34 to 45.

NATURE OF THE PRESSURE CHANGES.

There have been published a number of theories as to the origin and nature of the areas of rise and fall in pressure as shown by the pressure-change maps. Hanzlik in a paper on "Relations between velocities of lows and the areas of rising and falling pressure accompanying them" (MONTHLY WEATHER REVIEW, May, 1906, 34: 205) writes:

The results of the investigation on the relation of areas of falling and rising pressure to the lows are given by Sresnewsky:

(1) The center of the cyclone is always to the left of the point of most rapid fall of pressure. (2) This is explained as due to the greater eccentricity of the outer isobars of the cyclone and also due to the difference of barometric gradients on both sides of cyclones. (3) The area of most rapid decrease in the southeast quadrant of the cyclone coincides with the area of strongest storms and moves nearly parallel to the center of the cyclone. (4) There are cases when the area of fall moves apparently independently of the cyclone while the latter remains nearly stationary in the extreme north of Europe. These are the most important points in Sresnewsky's investigation that concern the relation of cyclones to the areas of fall and rise.

The atmospheric waves are, in Ekholm's opinion, very important phenomena. When there are strong storms in Swedish waters the areas of fall and rise follow similar tracks parallel to each other, while the cyclone keeps somewhat to the left of the track of the area of fall. When the cyclone reaches the land the intensity of the storm diminishes, the velocity of motion of the storm decreases, and the areas of fall and rise, with some delay, move in a southern or southwestern direction as if there were no apparent connection between them and the cyclonic area. The continued study of these areas of change in their relation to the cyclones led Ekholm to believe that for the weather and wind these are of greater importance than the cyclones themselves. "It seems to me highly probable," says Ekholm,² "that these oscillations are caused by the cyclones and anticyclones of higher levels, which sometimes but not always cause a corresponding cyclone or anticyclone on the surface of the earth." Worthy of mention is the cyclonic character of the area of fall, namely, the overcast sky and the occurrence of rain. Ekholm closes his paper with some remarks on the charts of change for other meteorological elements.

Hanzlik expressed a view concerning the areas of rise and fall that is quite different from that of Ekholm. He would bring the moving areas of falling and rising pressure into close connection with both the currents assumed to produce the lows. He associates the northerly winds with the areas of rise and the southerly warm winds with the areas of fall, (1) because the extreme temperature changes lie within the areas of rise and fall, and (2) because these two currents are assumed to be the primary cause which gives rise to the low.

The present writer is of the opinion that these areas of rising and falling pressure are not independent phenomena, although they may seem to be, but that they arise directly from the movements of and changes in pressure in highs and lows, with which they are associated. This, it is believed, is demonstrable and an effort will be made herein to show the truth of this statement.

OBSERVATIONS ON MAXIMUM PRESSURE-CHANGE AREAS.

One hardly needs to demonstrate the truth of the fact that a symmetrical low is, at any given moment, moving toward that point or region within its area where the pressure at the moment of observation is falling most rapidly. This maximum fall within the area of a low lies somewhere along a line passing through the center of the low and in the direction of advance of the low center and normal to the closed concentric isobars. The least change in pressure will be, of course, along two lines parallel to the direction of movement of the low, one on

² Ekholm, in *Meteorol. Ztschr.*, August, 1904, 21: 355.